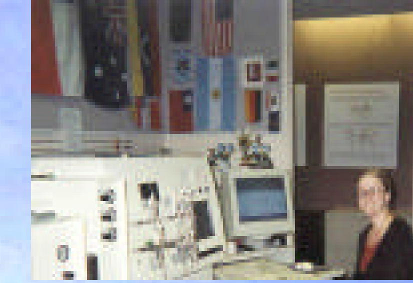
Stable isotopic variation across a precipitation gradient in Oregon:
Is _^{13}C of organic material a reliable predictor of water availability?



S.E. Reed[1], B. J. Bond[2], D. R. Bowling[1], N.G. McDowell[3], J. R. Ehleringer[1]

Global Change Education Program 2003

[1]Dept. Of Biology, University of Utah; [2]Dept. Of Forest Science, Oregon State University; [3]Earth and Environmental Sciences Division, Los Alamos National Laboratory

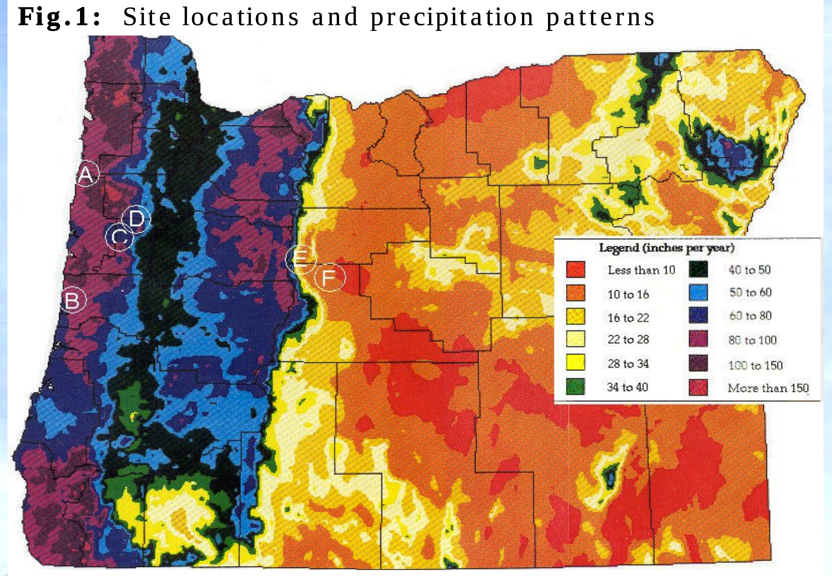
Introduction

Stable isotope analyses are useful tools in a wide variety of plant ecological and physiological research. During photosynthesis, plants discriminate against the heavier isotope of carbon (^{13}C). First, $^{13}CO_2$ diffuses more slowly through stomata, making the interior of the leaf slightly more depleted in $^{13}CO_2$. Furthermore, the primary carboxylating enzyme in C3 plants, Rubisco, preferentially fixes $^{12}CO_2$. Thus measurements of carbon isotopic composition of leaf tissue (_$^{13}C_f$) can reflect environmental conditions and plant metabolism.

Several studies have explored foliar _^{13}C across precipitation gradients. For example, Stewart, *et al.* (1995) found a linear increase in community averaged _$^{13}C_f$ with decreasing annual rainfall across a 1300 mm precipitation gradient. This result supports the notion that as plants become more water stressed, less discrimination occurs. However, Schulze, *et al.* (1998) concluded that _$^{13}C_f$ was approximately constant at rainfalls above 475 mm across a 1600mm precipitation.

This study is an attempt to shed light on those contrasting results and to try to infer the mechanisms controlling _^{13}C within various ecosystem processes. We made use of the OTTER Transect (Oregon Transect for Terrestrial Ecosystem Research) (Fig. 1) to study the isotopic composition of foliage, roots, and soil organic matter across a precipitation gradient.

Fig.1: Site locations and precipitation patterns



Materials and Methods

Site Characteristics

- Six sites (A-E) located along the OTTER Transect, ranging from most wet (A) to most dry (E)
- Mean annual precipitation varies from 227mm to 2760mm for a total gradient of 2533mm across a 250km stretch of land
- Stand ages range from 15 years to 250 years
- Canopy heights range from 8m to 50m
- Elevations range from 240m to 941m
- Dominant species at the six coniferous forest sites include
  - *Picea sitchensis* (Sites A&B)
  - *Tsuga heterophylla* (A&B)
  - *Pseudotsuga menziesii* (C&D)
  - *Pinus ponderosa* (E)
  - *Juniperus occidentalis* (F)

Organic sampling

- Foliage: As many species sampled per site as possible (1-5 individuals per species), with 66 different species sampled total
- Current year's growth and sun foliage collected for all tree samples; shade needles were also collected for some trees.
- Soil: Three soil pits were excavated at each site; samples were collected in 5-cm depth increments, down to 25 cm.
- Litter: Litter was divided into fresh litter and old litter (significant decomposition, but still recognizable as needles).
- Roots: Roots were removed from the soil samples.

Sample analyses

- All samples were oven dried in the laboratory (70°C)
- Samples finely ground to No. 20 mesh
- 556 samples combusted and analyzed for _$^{13}C_f$, _^{15}N, %C, and %N on an Isotope Ratio Mass Spectrometer (deltaS: Finnigan MAT) at the University of Utah

Climate data

- Climate data provided by Oregon Climate Service at Oregon State University
- PRISM model (Daly et al. 1994 & 1997) applied to better estimate the mean annual precipitation at each site

Acknowledgements

Thanks to everyone at GCEP for making this opportunity possible: Jeff Gaffney, Milt Constantin, Mary Kinney, Pat Shoulders, Peter Lunn

Muchas gracias to everyone at Oregon State University for their assistance and insight: Barbara Bond, Nate McDowell, and Laura White

And thanks to all those at the University of Utah SIRFER Lab: Jim Ehleringer, Dave Bowling, Craig Cook, Mike Lott, Suzanne Bethers, John Howa, Brian Newson, Trisha Fredley, Chrystal Smith, Brenda Hoover, The Hulk, and a whole lot more.

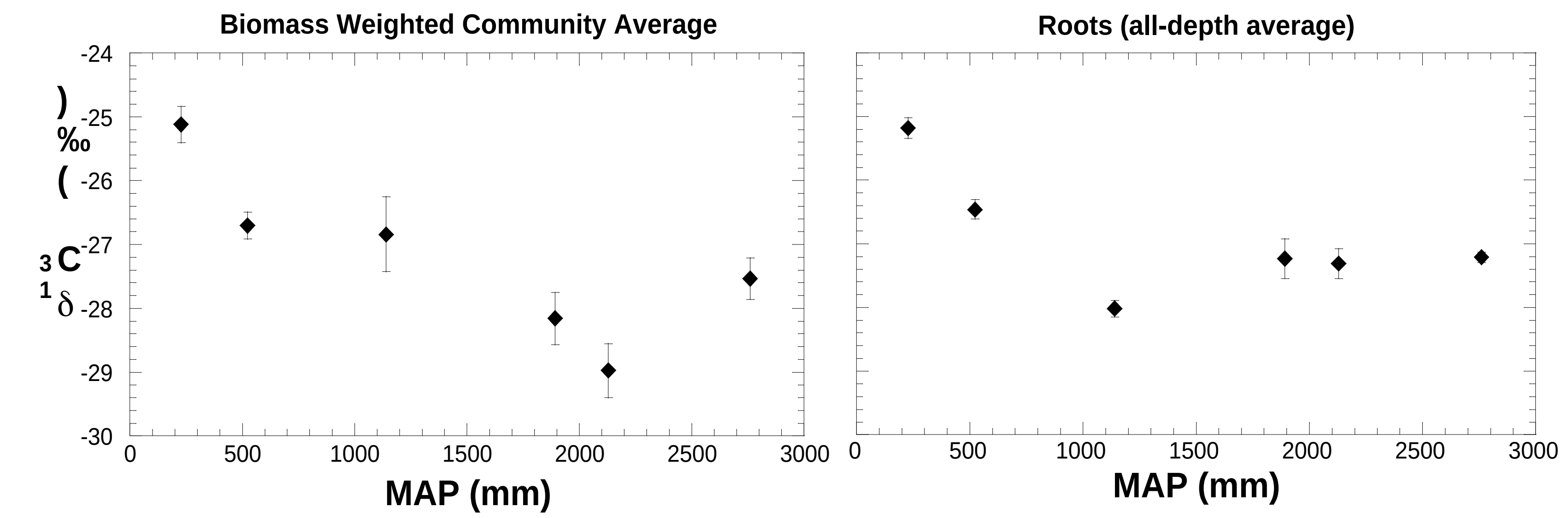


Figure 2: Biomass weighted community averages and all-depth averages for foliage and roots, respectively, at each site, versus mean annual precipitation. For the foliage, we applied a weighted average based on estimated relative contributions of overstory (90%) and understory (10%) biomass (R. Waring, personal communication 2002). The overall trend was a linear decrease, similar to Stewart *et al.*'s results. It should be noted, however, that the wettest site, Site A, exhibited results contrary to expectation, i.e., although it is the wettest site, it did not have the most negative _$^{13}C_f$ values. One possible explanation may be that the stand is hydraulically limited due to its size (Ehleringer *et al.* 1998; Yoder *et al.* 1994). Hydraulic limitations have been shown to affect stomatal conductance (Hubbard, *et al.* 1999), which will, in turn, affect _$^{13}C_f$. Root values are the mean value of all five depths sampled. Sites A & D were sampled in 2002. All other sites were sampled in 2000.

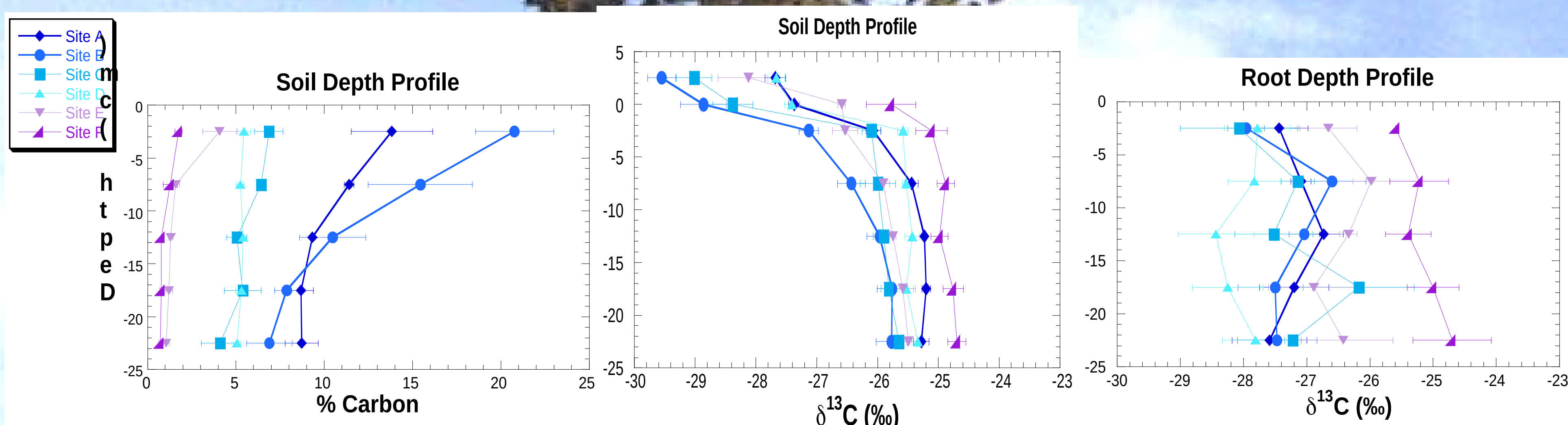


Fig. 3: Mean values of % Carbon of bulk soil organic matter (SOM) and δ^{13}C of SOM, forest litter, and roots, in 5-cm depth increments. There was no fresh litter at Site F during sampling. Sites A & D were sampled in 2002. All other sites were sampled in 2000.

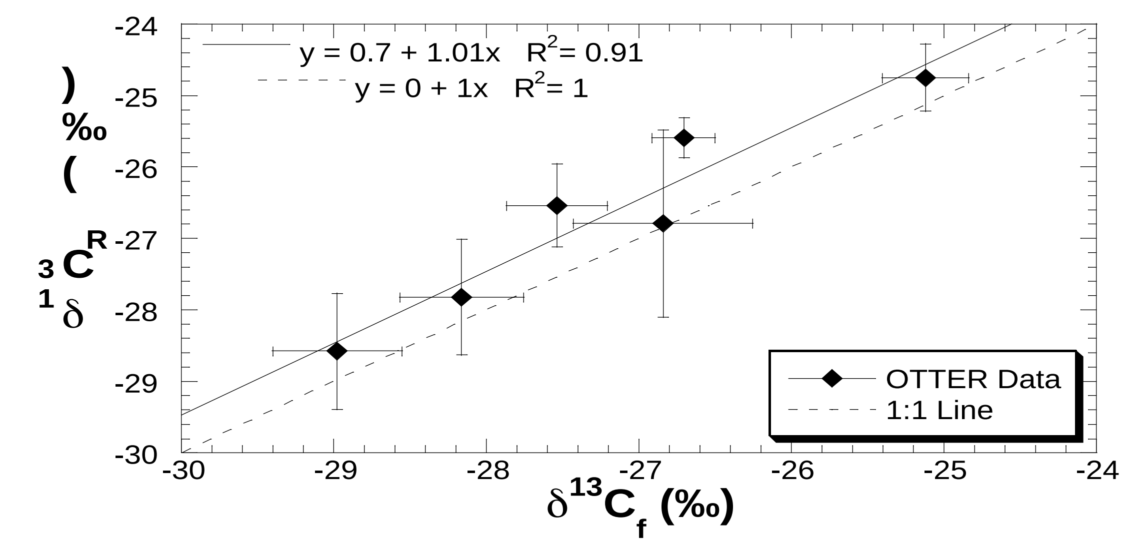


Fig. 4: _^{13}C of ecosystem respiration (_$^{13}C_R$) vs. _^{13}C of foliage (_$^{13}C_f$). _$^{13}C_R$ data were determined using air samples collected from the six OTTER sites in 2000 (Bowling, *et al.* 2002). The foliage data are the 90%/10% biomass-weighted community averages from the 2002 samples. There is a noticeable offset from the 1:1 line. Two possible explanations are differences in types of organic molecules respired (lipids, for example, are lighter than carbohydrates) or fractionation during biosynthetic reactions that occur after photosynthesis (Pataki et al. 2002).

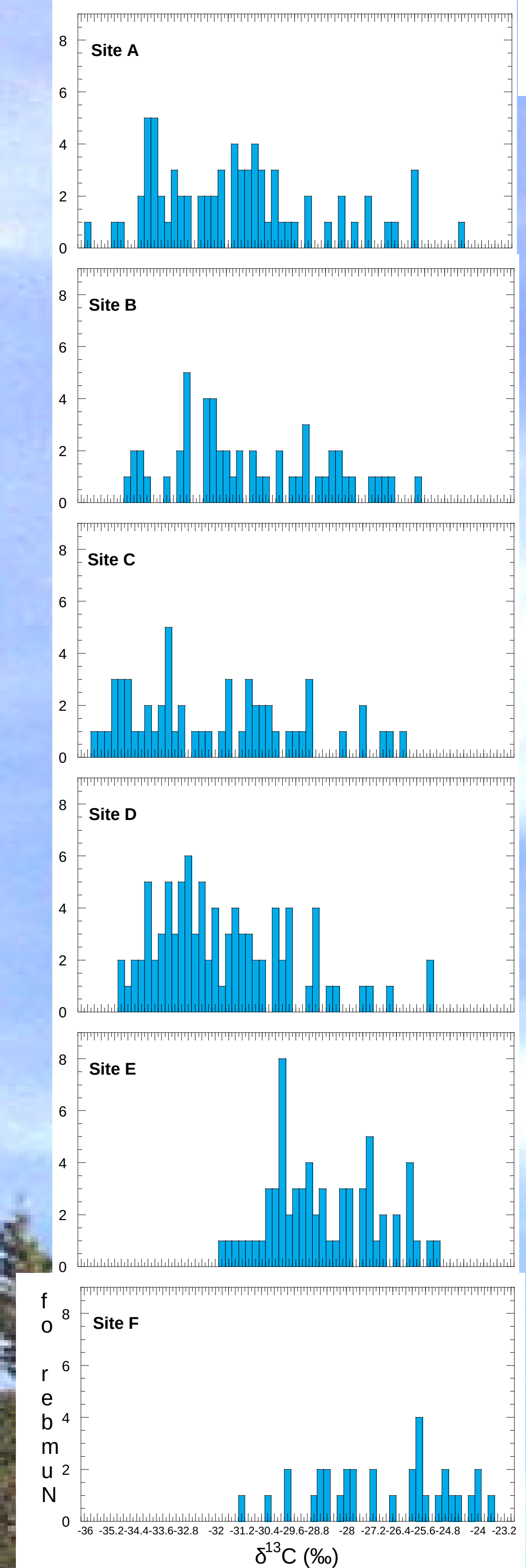


Fig. 5: Site-by-site inventory of δ^{13}C foliage values. All 556 samples are included in this compilation. Again, sites range from most wet (A) to most dry (E).

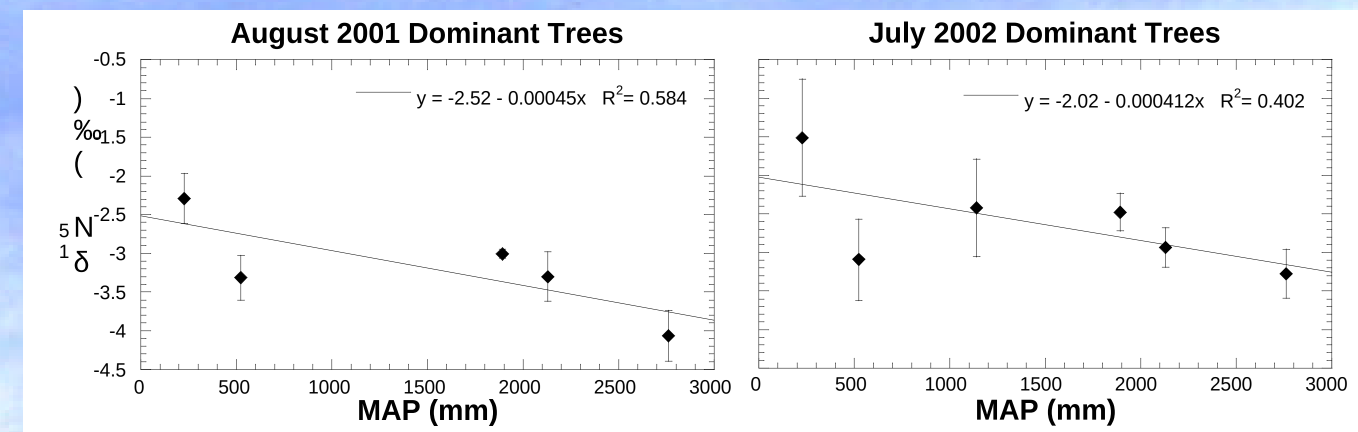


Fig. 6: Mean δ^{15}N values of the dominant trees at each site for two consecutive years. Site D was not sampled in 2001.

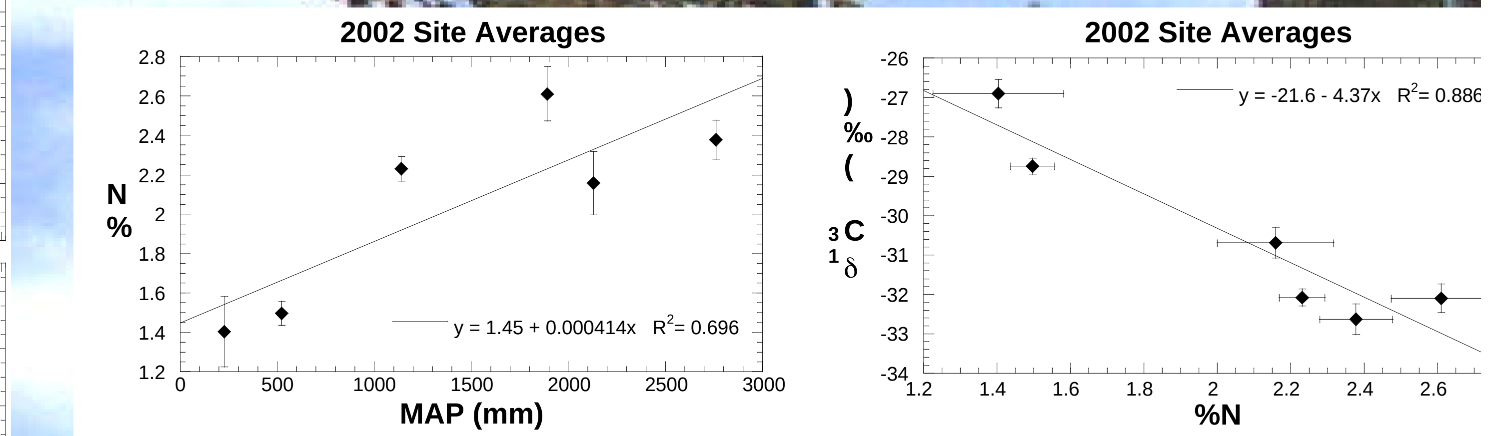


Fig. 7: Mean nitrogen concentration (%N) vs. mean annual precipitation and %N vs. _$^{13}C_f$. (%N and _$^{13}C_f$ are unweighted average values of all foliage samples at each site.) There was a strong negative correlation between the %N and _$^{13}C_f$. Although the results are opposite of what theory predicts (Field and Mooney, 1983), others (Vitousek *et al.* (1990) and Schulze *et al.* (1998)) have found results similar to those above.

Conclusion

The relationship between community-averaged _$^{13}C_f$ and precipitation across the transect may lead to the use of _$^{13}C_f$ as an indicator of environmental influences on plant functioning. However, the discrepancies between studies such as Stewart *et al.*'s (1995) and Schulze *et al.*'s (1998) must still be resolved before any generalizations can be made. The correlation between _$^{13}C_R$ and _$^{13}C_f$ is intriguing in that _$^{13}C_f$ might become useful in predicting ecosystem respiration, which is important in estimations of the global carbon budget. The pattern of decreasing foliar δ^{15}N with increasing mean annual precipitation was consistent over two years and has been observed in a number of other studies world-wide (Handley *et al.* 1999). This suggests that annual rainfall input may play a significant role in controlling ecosystem nitrogen cycling.

Since most other studies have focused on the variation of _$^{13}C_f$ within a single species or a single plant functional type, we sampled as wide a variety of species and plant functional groups as possible in attempt to gain a better understanding of the differences of isotopic composition across plant functional groups. We are currently working to examine the differences in isotopic composition with respect to plant functional types and other parameters.

References

Bowling, David R., *et al.* ^{13}C content of ecosystem respiration is linked to precipitation and vapor pressure deficit. Oecologia 2002, 131: 113-124.

Daly C, *et al.* A statistical-topographic model mapping climatological precipitation over mountainous terrain. Journal of Applied Meteorology 1994, 33: 140-158.

Daly C., *et al.* The PRISM approach to mapping precipitation and temperature. 10th Conference on Applied Climatology, Reno Nevada American Meteorological Society, Boston, Mass. 1997, 10-12.

Ehleringer, J. R. and Cook C.S. Carbon and oxygen isotope ratios of ecosystem respiration along an Oregon conifer transect: preliminary observations based on small-flask sampling. Tree Physiology 1998, 18: 513-519.

Handley, L.L., *et al.* The 15-N natural abundance (δ^{15}N) of ecosystem samples reflects measures of water availability. Australian Journal of Plant Physiology, 26: 185-199.

Hubbard R.M., *et al.*, Evidence that hydraulic conductance limits photosynthesis in old *Pinus ponderosa* trees. Tree Physiology 1999, 19: 165-172.

Pataki, D.E., *et al.* The application and interpretation of Keeling plots in terrestrial carbon cycle research. Accepted: Global Biogeochemical Cycles.

Schulze, E.D., *et al.* Carbon and nitrogen isotope discrimination and nitrogen nutrition of trees along a rainfall gradient in northern Australia. Australian Journal of Plant Physiology 1998, 25: 413-425.

Stewart, George R., *et al.* ^{13}C natural abundance in plant communities along a rainfall gradient: a biological integrator of water availability. Australian Journal of Plant Physiology 1995, 22: 51-55.

Vitousek, Peter M., *et al.* Variation in foliar _^{13}C in Hawaiian *Metrosideros polymorpha*: a case of internal resistance? Oecologia 1990, 84: 362-370.

Yoder, B.J., *et al.* Evidence of reduced photosynthetic rates in old trees. Forest Science 1994, 40: 513-527.